



Electricity for Road-transport, Flexible Power Systems and Wind Power

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VPPC 2011

6.-9. September 2011 Chicago

Results from a study on:

Electricity for Road-transport Flexible power systems and wind power

http://www.risoe.dtu.dk/en/Research/sustainable_energy/energy_systems/projects/SYS_G2V2G.aspx

Lars Henrik Nielsen

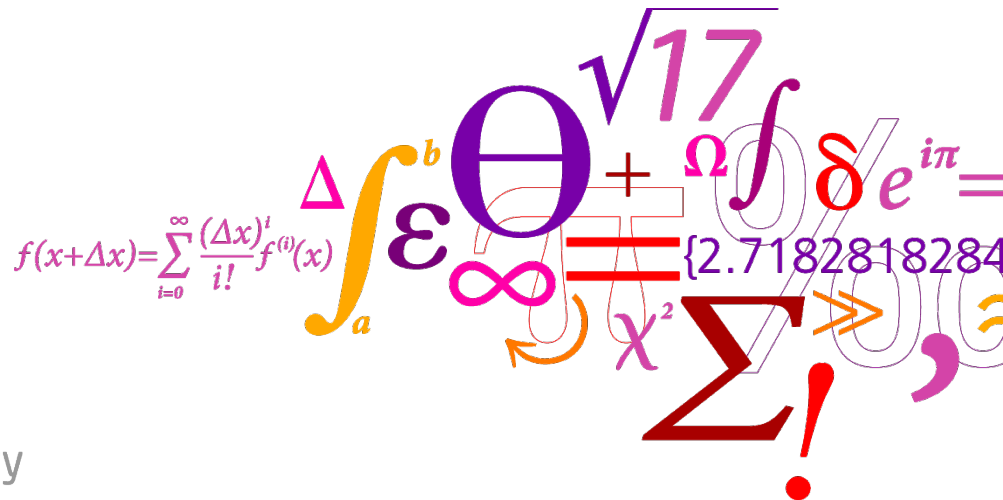
Senior scientist

SYS Risø DTU

Denmark

Risø DTU

National Laboratory for Sustainable Energy



Project title:

Electricity for Road Transport Flexible Power Systems and Wind Power

Project aim:

To analyse the **potential synergistic interplay** that may arise between the **power sector and the transport sector**, if segments the road transport are based on **plug-in hybrid electric vehicles and pure electric vehicles**, for integrating fluctuating power production, such as wind power.

Partners:

- Risø National Laboratory for Sustainable Energy. Technical University of Denmark (DTU) **Systems Analysis Division** and the IES Programme.
- Technical University of Denmark (DTU). Centre for Electric Technology, Department of Electrical Engineering.
- RAM-løse edb (expertise on optimisation models / Balmorel)
- Energinet.dk, Planning & Scenarios and Analysis & Methods (Danish **TSO**)
- Danish Energy Association (Includes Danish **DSOs**)

Main sponsor: **EUDP** (Danish Energy Development and Demonstration Programme)

Project duration: 3.5 years

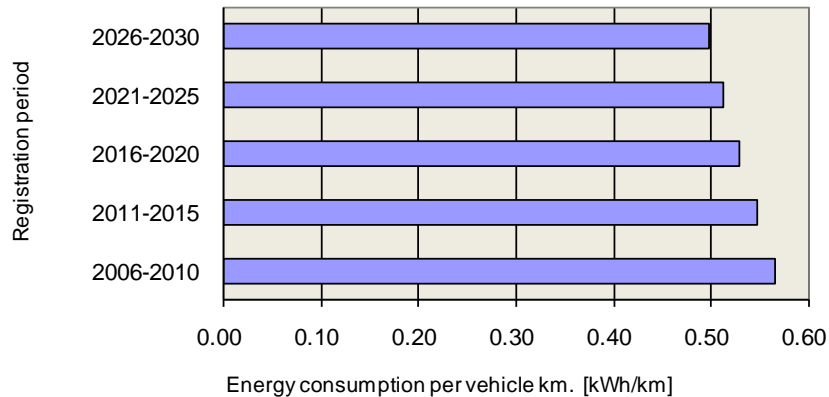
Content: Touch upon

- **EV technology development assumptions**
(Segment: Passenger cars and delivery vans < 3.5 ton)
- **Scenarios set up for Denmark** (population of about 5.5 mio.)
(via EPRI medium scenario assumptions from 2007 for market penetration. **Mainly focus on PHEVs.**)
- **Power Distribution system aspects (DSO)**
- **Power Transmission system issues (TSO)**
- **Overall (north European) power system: Future development with EVs ..**
Results via the power system optimisation models (including transport modules)
 - Balmorel** (market, system operation and development (investments)) and
 - Wilmar** (spot and intraday markets, system operation, stochastic production)

Vehicle energy consumption: kWh/km

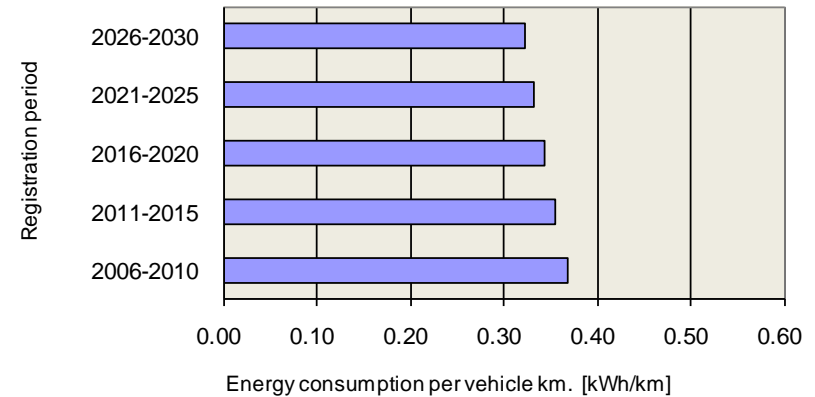
ICEV fuel consumption:

Specific energy consumption for fleet average **ICEV**
Passenger cars and delivery vans <3.5t. Reference



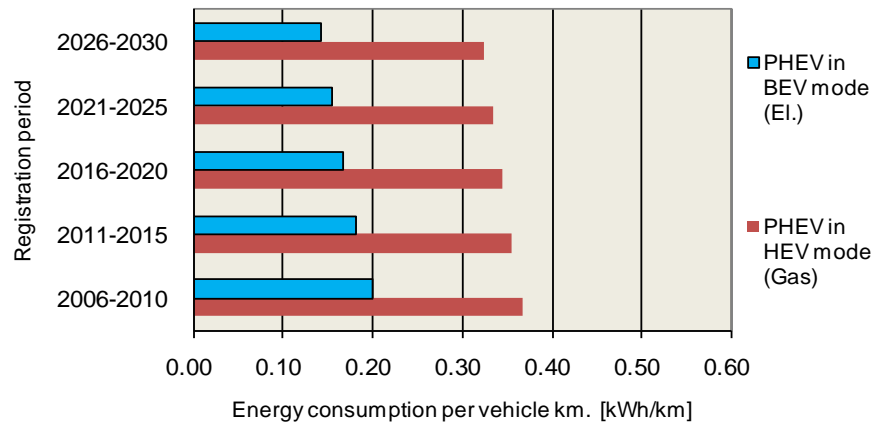
HEV fuel consumption:

Specific energy consumption for fleet average **HEV**
Passenger cars and delivery vans <3.5t. Reference



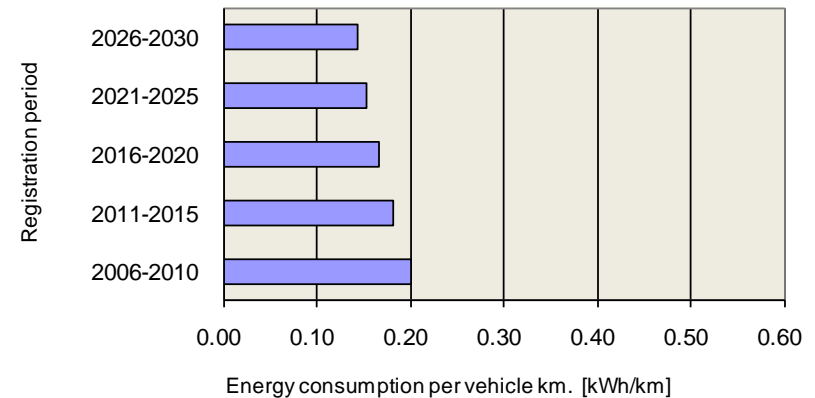
PHEV electricity and fuel consumption:

Specific energy consumption for fleet average **PHEV**
Passenger cars and delivery vans <3.5t. Alternative



BEV electricity consumption:

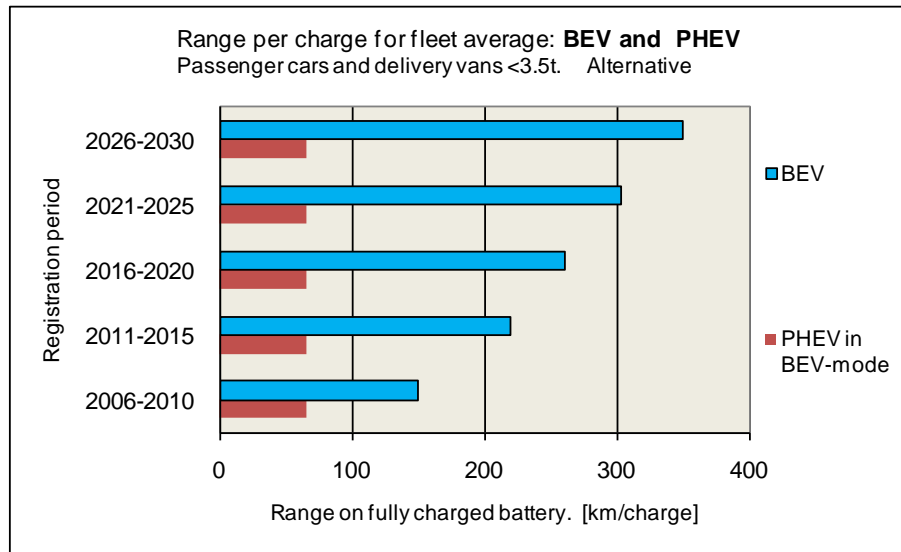
Specific energy consumption for fleet average **BEV**
Passenger cars and delivery vans <3.5t. Alternative



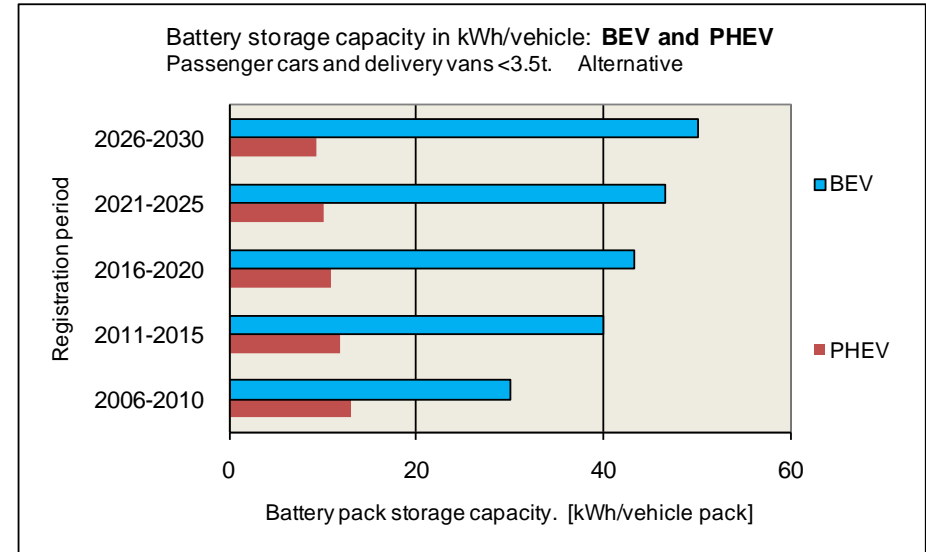
Electric Vehicle:

Battery size and range per charge

PHEV & BEV: Range [km/charge]



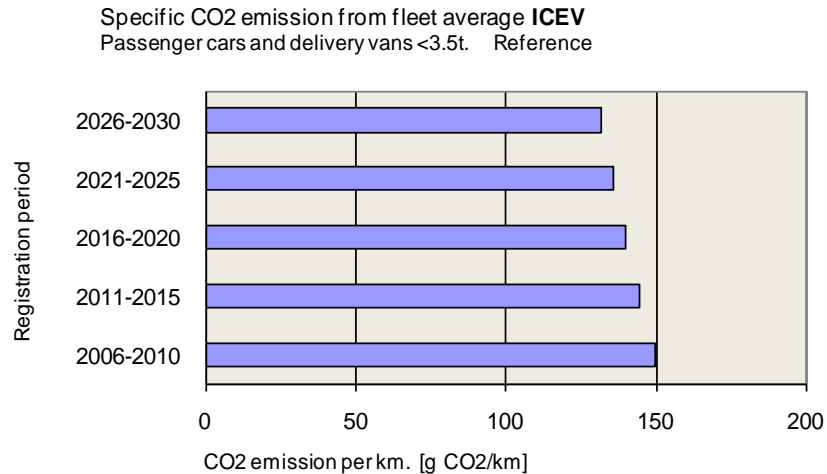
PHEV & BEV: Battery size [kWh/pack]



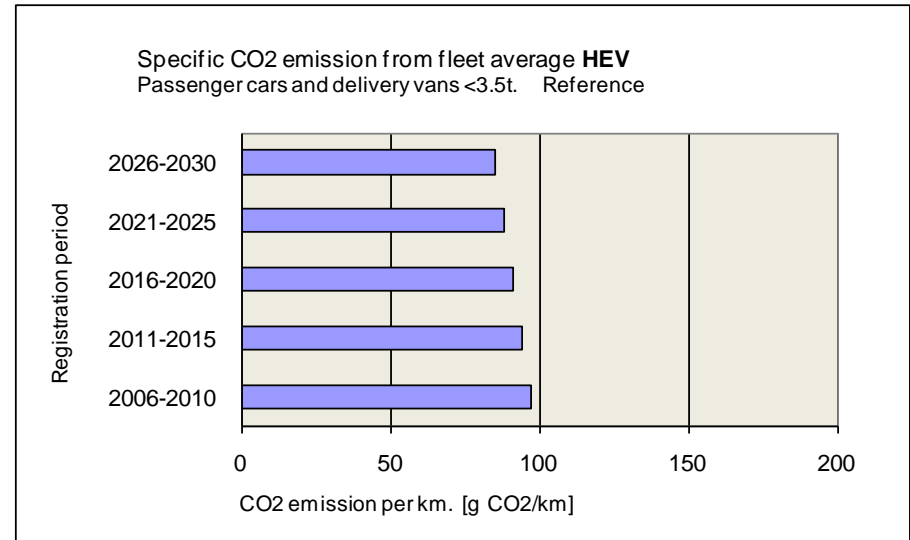
Vehicle specific CO₂ emission: g CO₂ /km

CO₂Case I : Marginal el-production in DK (coal) Source: DEA (2010)

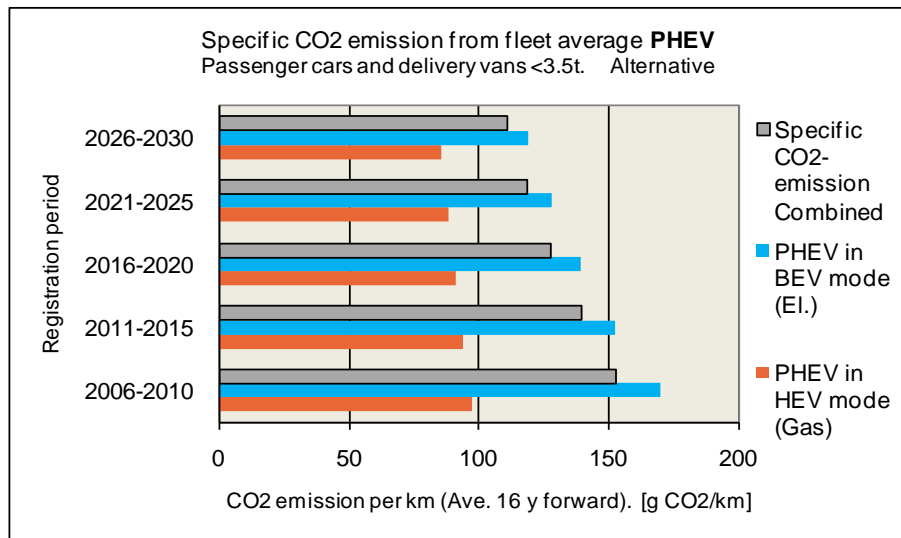
ICEV CO₂ emission:



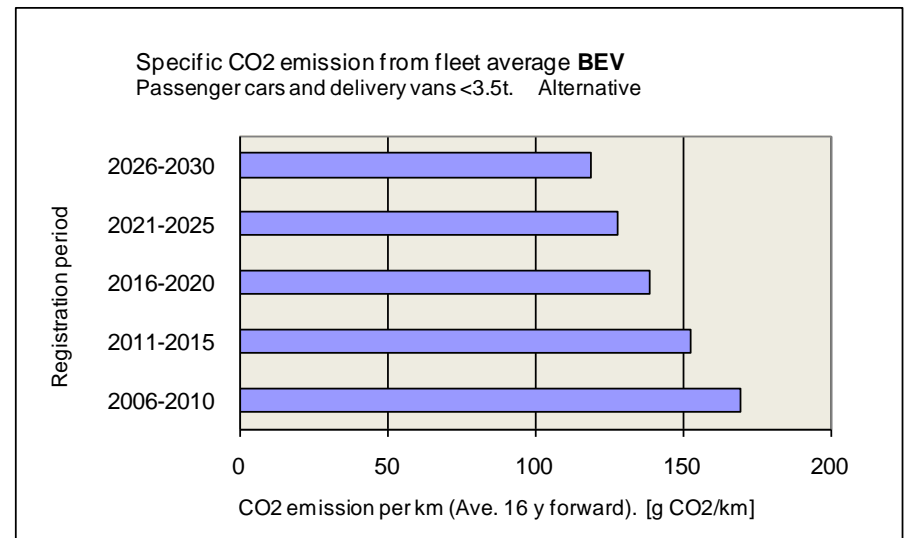
HEV CO₂ emission:



PHEV CO₂ emission: CO₂Case I



BEV CO₂ emission: CO₂Case I

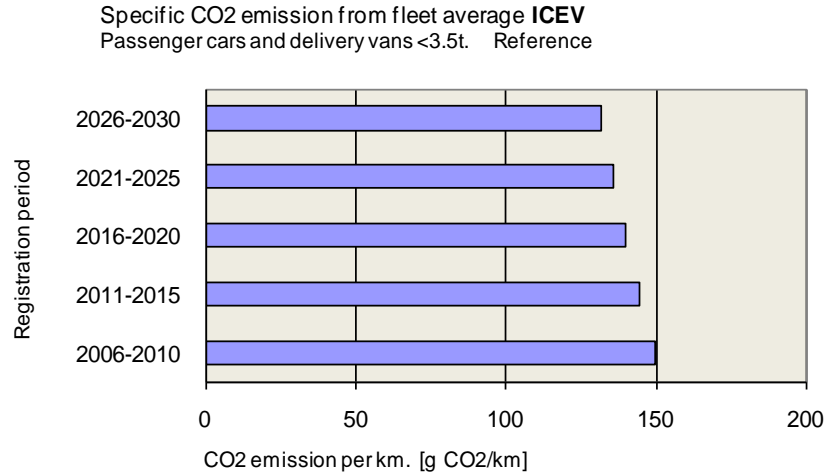


Vehicle specific CO₂ emission: g CO₂ /km

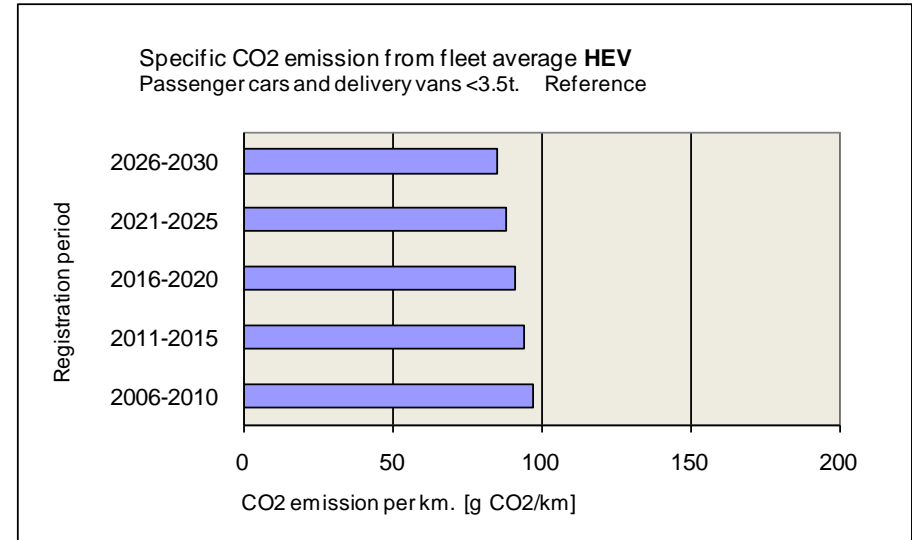
CO₂Case III : Average power system CO₂-characteristics.

And linear phasing out to zero of all fossil fuels by 2050. (Stated Danish aim, October 2010.)

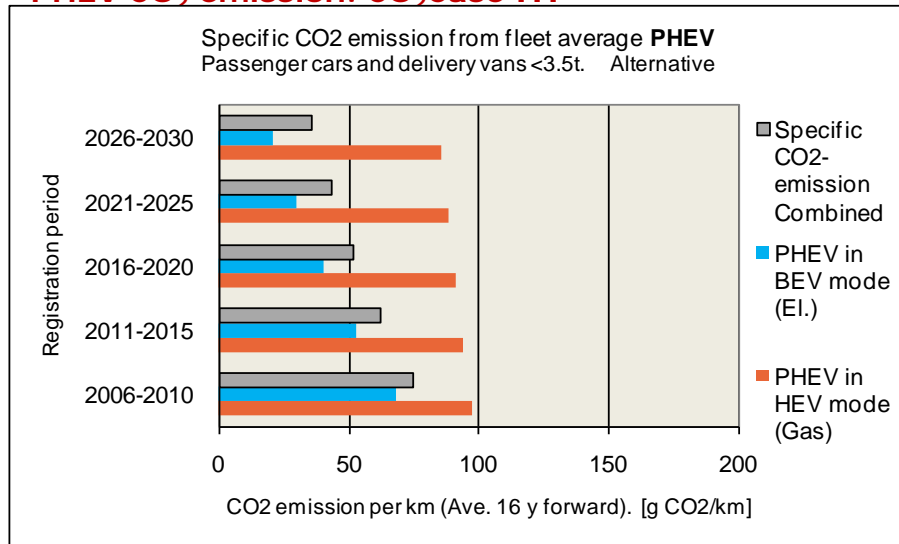
ICEV CO₂ emission:



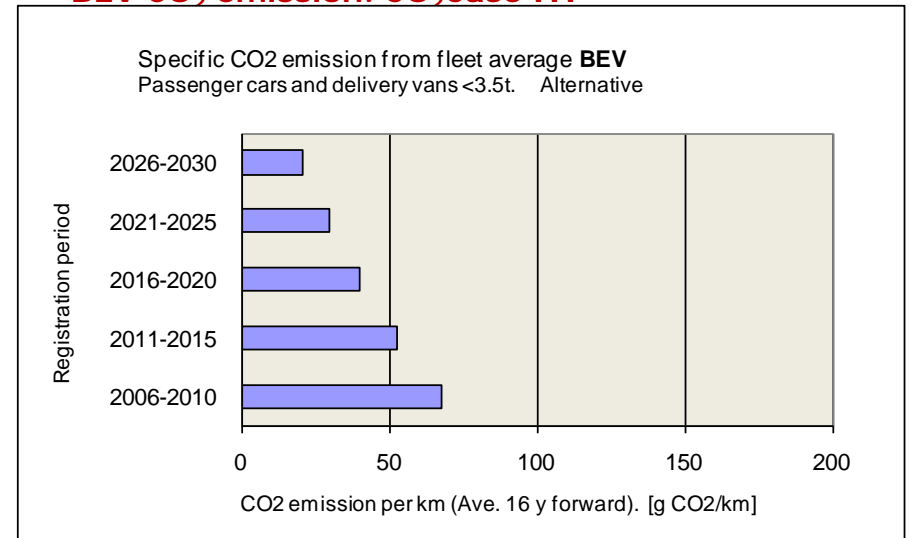
HEV CO₂ emission:



PHEV CO₂ emission: CO₂Case III

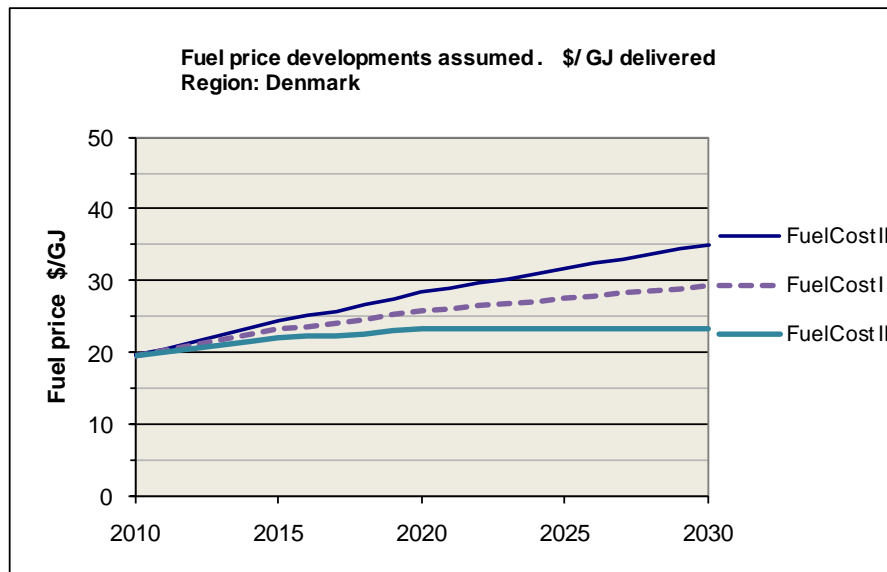


BEV CO₂ emission: CO₂Case III

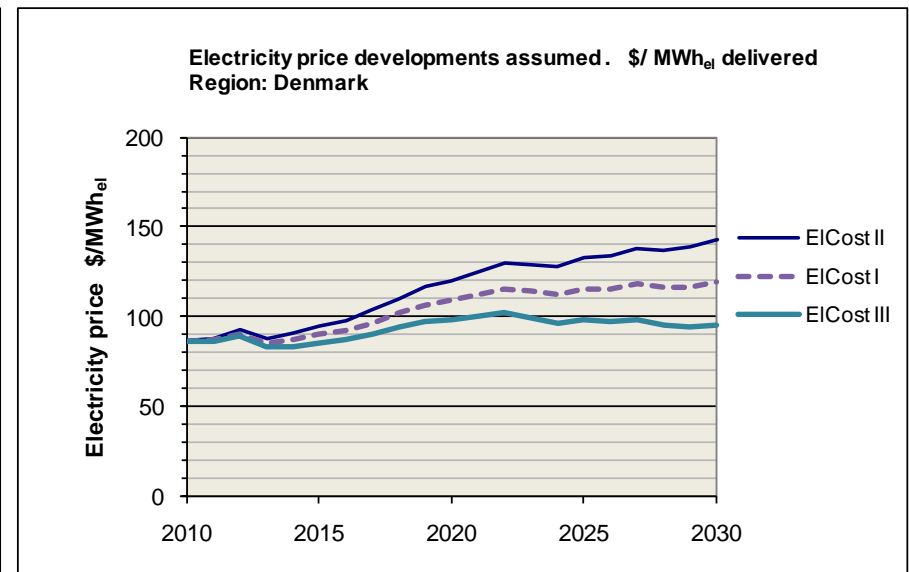


Energy price developments assumed for fuel (gasoline/diesel) and electricity.

Fuel-Cost I, II and III



EI-Cost I, II and III



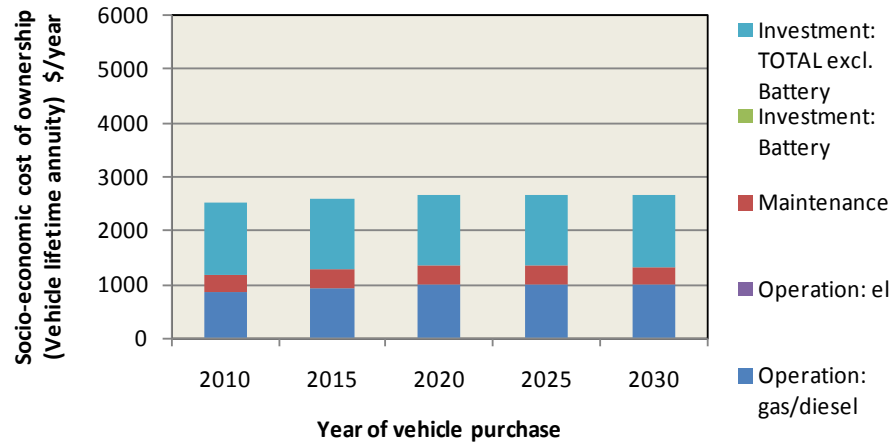
Vehicle cost of ownership: \$/year

EV battery cost: USDOE July 2010 Scenario



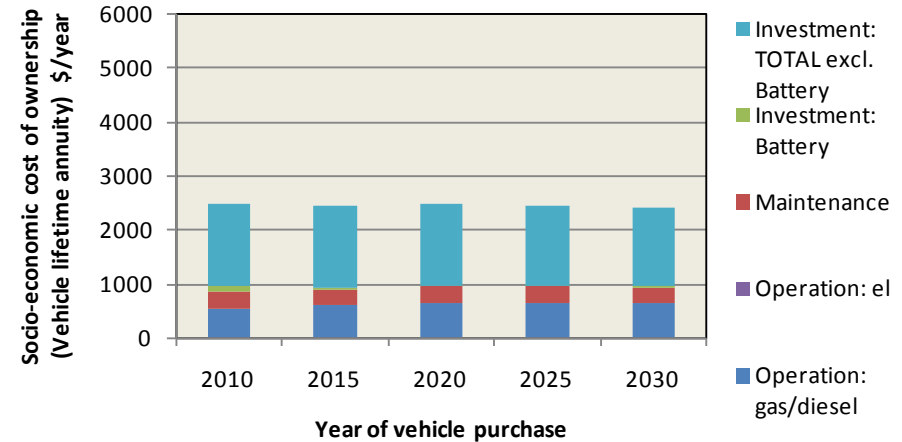
ICEV:

Socio-economic cost of ownership: ICEV Reference



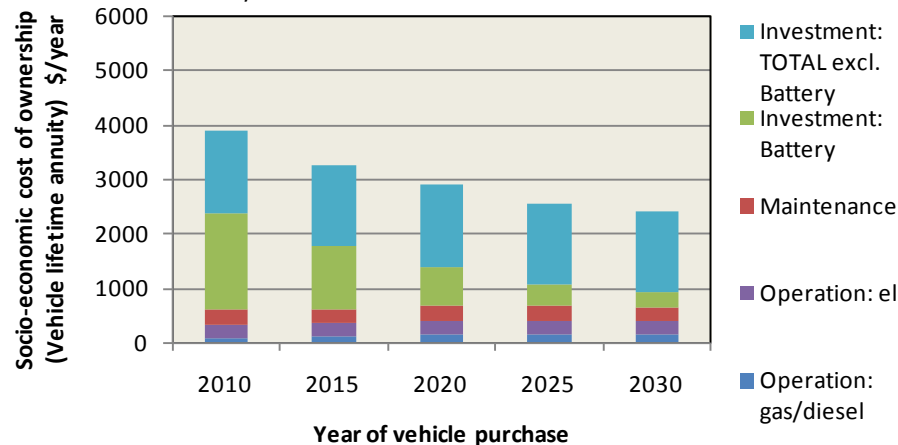
HEV:

Socio-economic cost of ownership: HEV Alternative



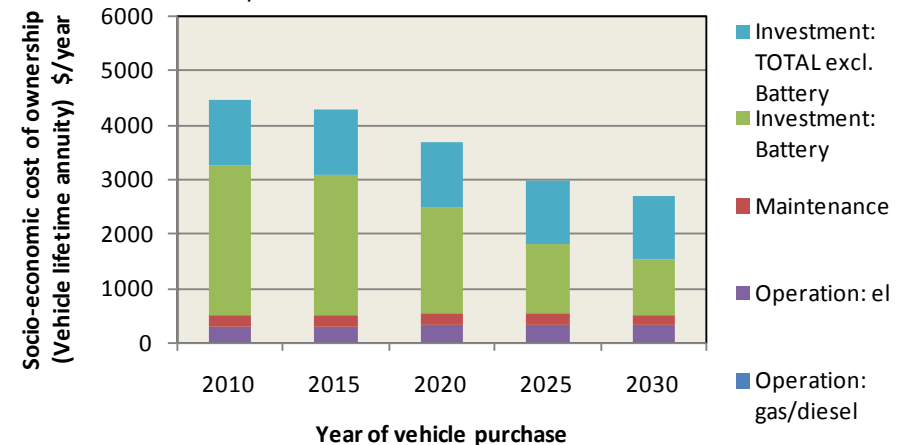
PHEV: BatCost I, COWI (2007) & IEA (2009)

Socio-economic cost of ownership: PHEV Alternative
Battery cost data: BATCost I



BEV: BatCost I, COWI (2007) & IEA (2009)

Socio-economic cost of ownership: BEV Alternative
Battery cost data: BATCost I



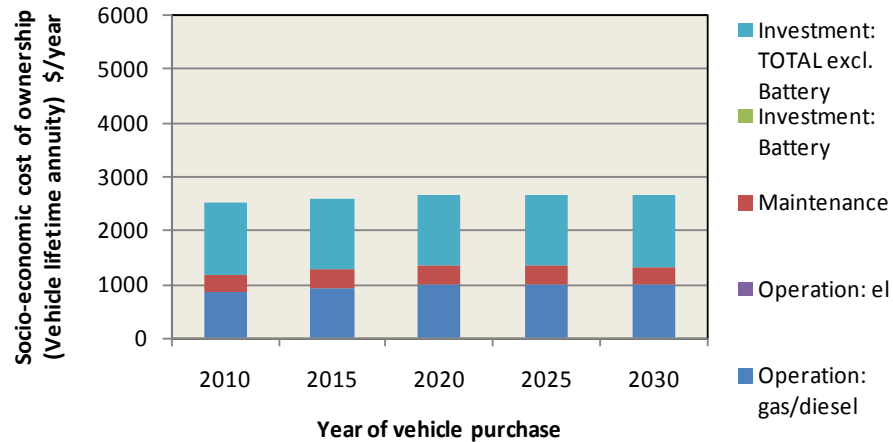
Vehicle cost of ownership: \$/year

EV battery cost: USDOE July 2010 Scenario



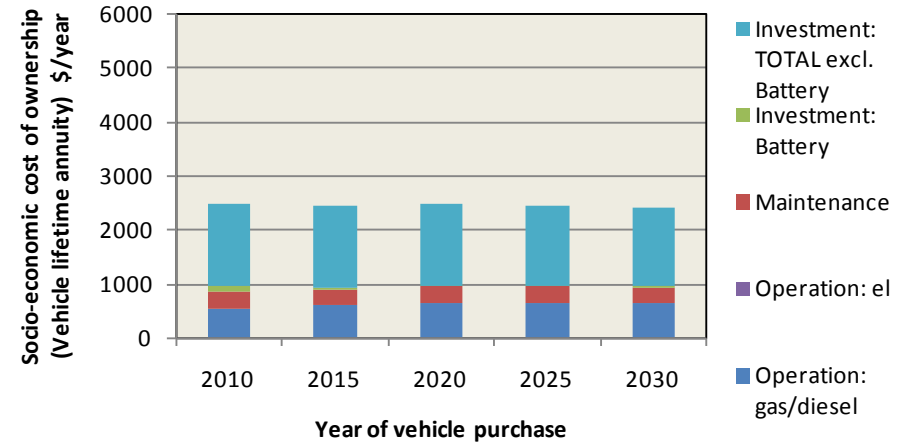
ICEV:

Socio-economic cost of ownership: ICEV Reference



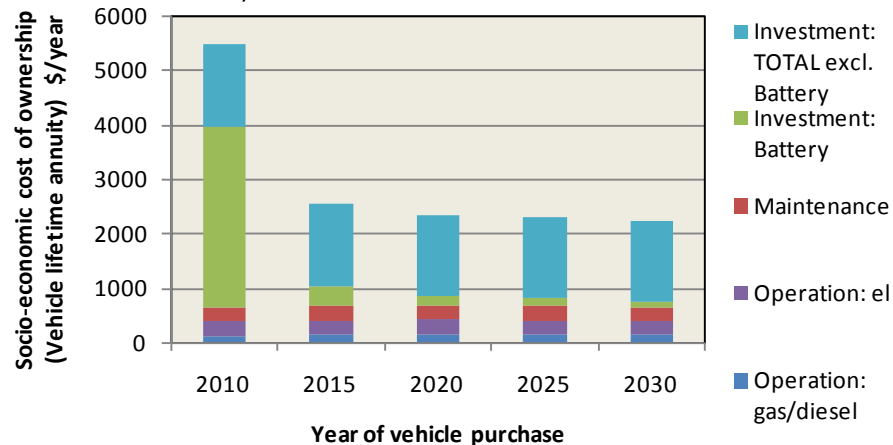
HEV:

Socio-economic cost of ownership: HEV Alternative



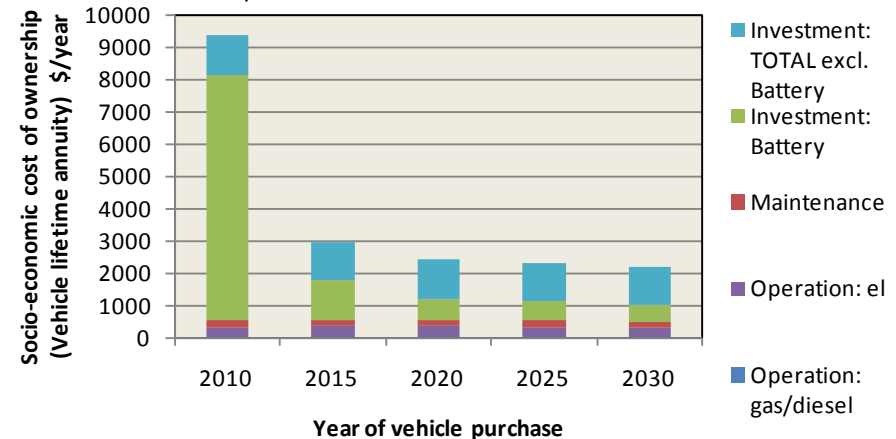
PHEV: BatCost II, US DOE 2010 scenario

Socio-economic cost of ownership: PHEV Alternative
Battery cost data: BATCost II



BEV: BatCost II, US DOE 2010 Scenario

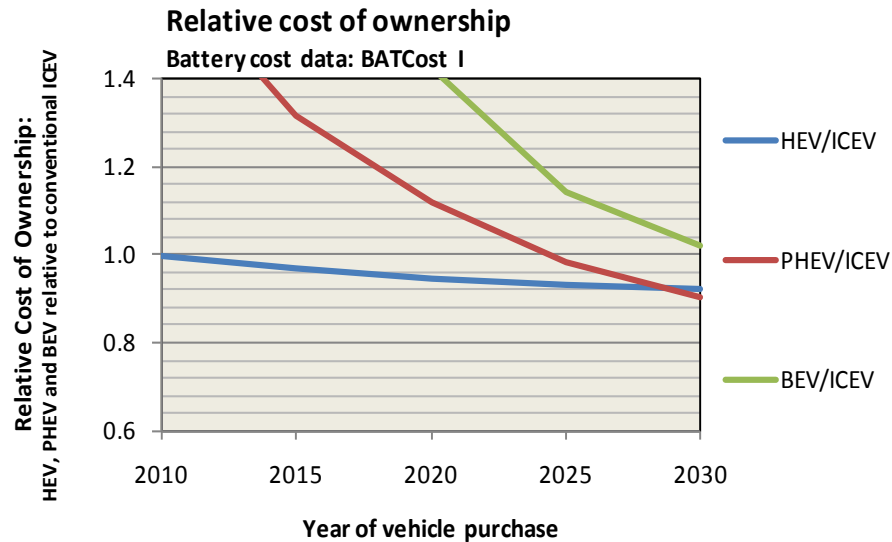
Socio-economic cost of ownership: BEV Alternative
Battery cost data: BATCost II



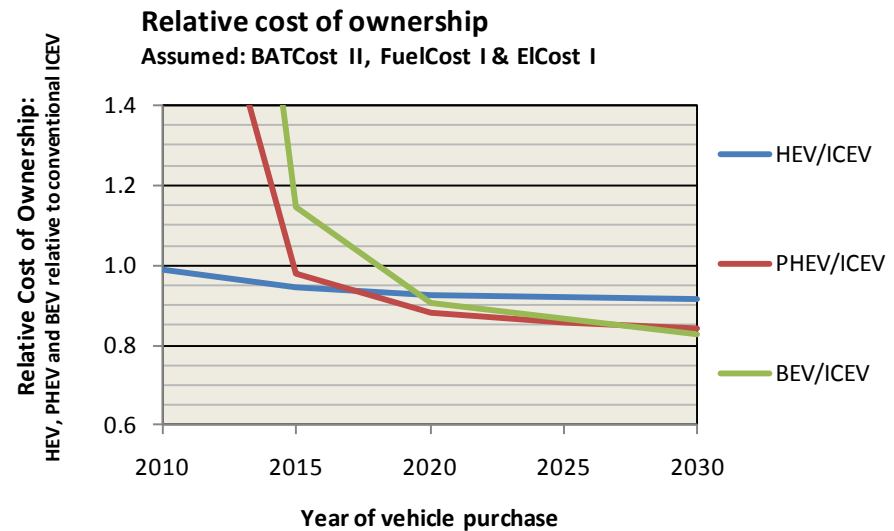
Relative cost of ownership: $(\$/\text{year}) / (\$/\text{year})$

BEV, PHEV, HEV / ICEV

BatCost I : DK DEA 2010 scenario



BatCost II: US DOE 2010 Scenario



Conclusion: Individual EVs

Energy & CO₂ emission

Energy:

- **Electricity substitutes gasoline/diesel** via the EV.
- **EV drive trains** have potential for being very **energy efficient**.
- 3000 kWh electricity may sustain about 20.000 km average vehicle driving.
- Via EVs segments of the transport sector can **diversify its energy resource base** and reduce dependency on oil based fuels.

CO₂ emission:

- **EV CO₂ emission relates to the power supply** system charging the vehicles. The EV footprint of the individual vehicle change in accordance with the power supply.
- According to the Danish 'reference' development for the marginal power supply EVs bring almost **insignificant CO₂ reduction (due to coal dominated marginal power production)**. However, assuming linear descend to zero CO₂ emission in 2050 for the power supply substantial CO₂ reduction is achieved via EVs substituting ICEVs. Ultimately EVs may provide zero CO₂ emission road transport.
- The individual ICEV of today may emit **about 2-3 ton CO₂ /year. This equals max achievable EV CO₂ reduction.**

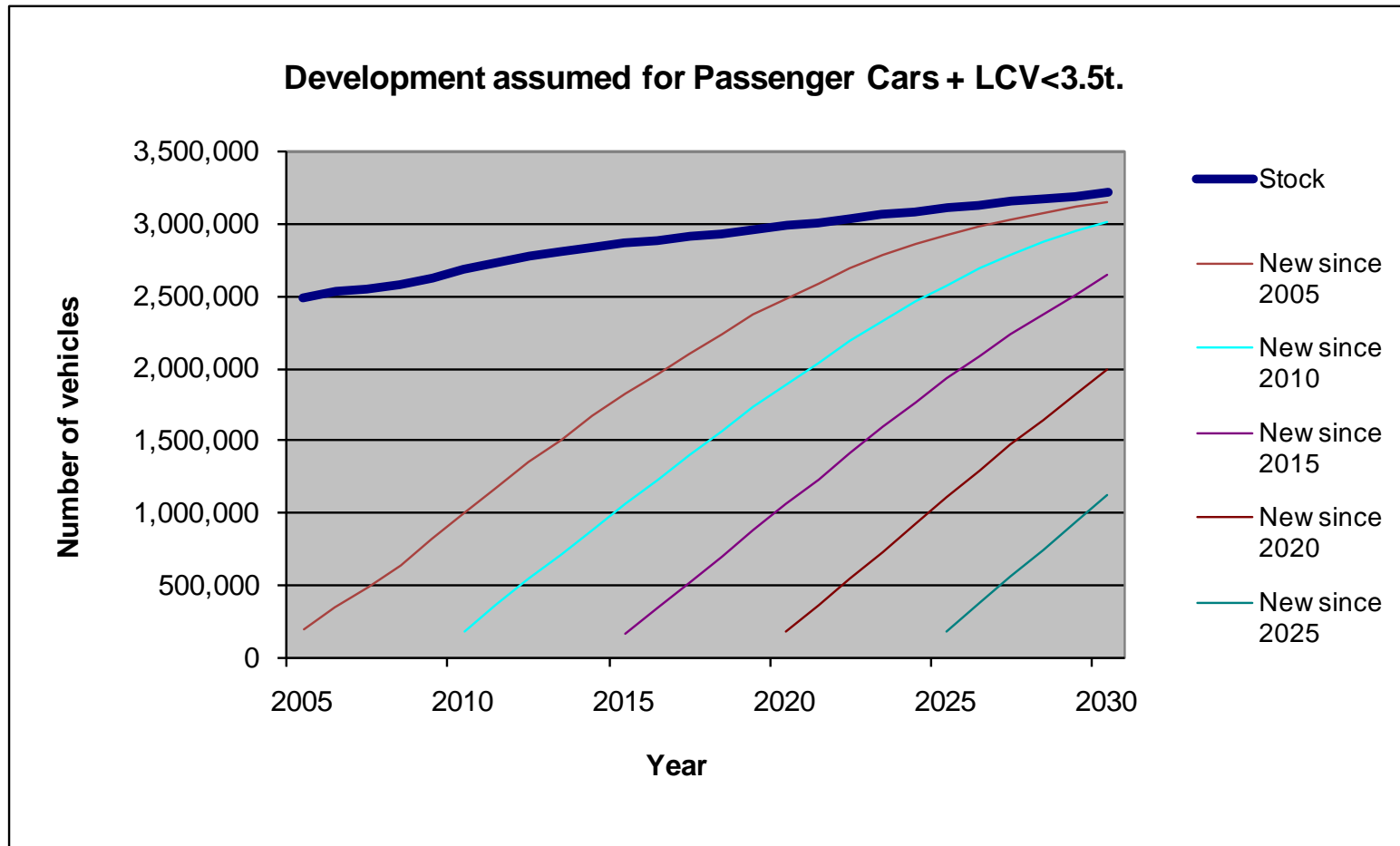
Conclusion: Individual EVs

Economy:

- Cost and lifetime of **EV batteries much determine the EV economy**. Based on (marginal and partial) socio-economic costs of ownership.
- In 'reference' battery cost development: **PHEVs may get break-even with the ICEV beyond year 2020**. (COWI (2007) & IEA (2009))
- In 'alternative' battery cost development: **PHEVs may get break-even with the ICEV year 2015**. (DOE, The Recovery Act: Transforming America's Transportation Sector, Batteries and Electric Vehicles, July 14, 2010.)
- CO₂ emission allowance **costs for 2-3 ton CO₂ are small put relative to costs of vehicle ownership**. May not constitute incentive for vehicle purchase.

Danish fleet: Vehicle/fleet renewal

Segment: Passenger Cars + LDV < 3.5t

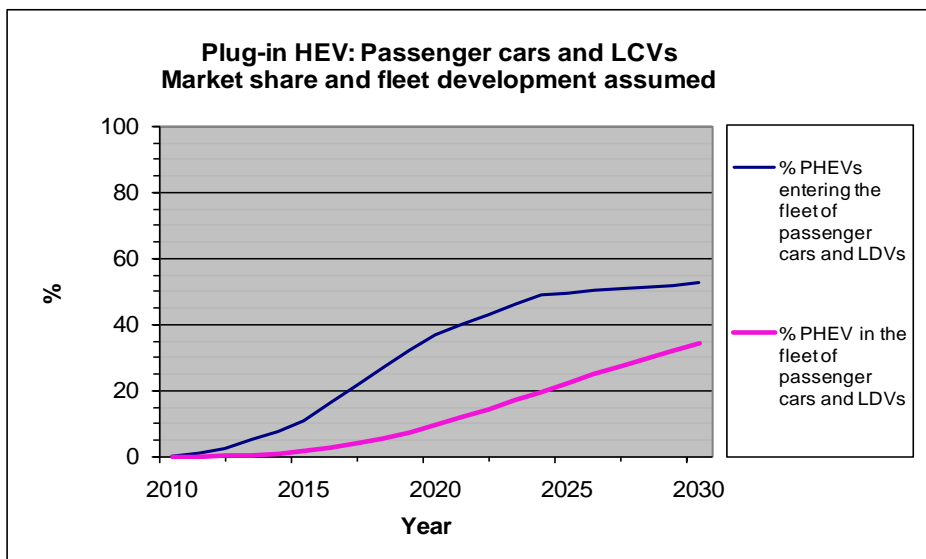


Danish fleet: PHEV Scenario: Market share & fleet development

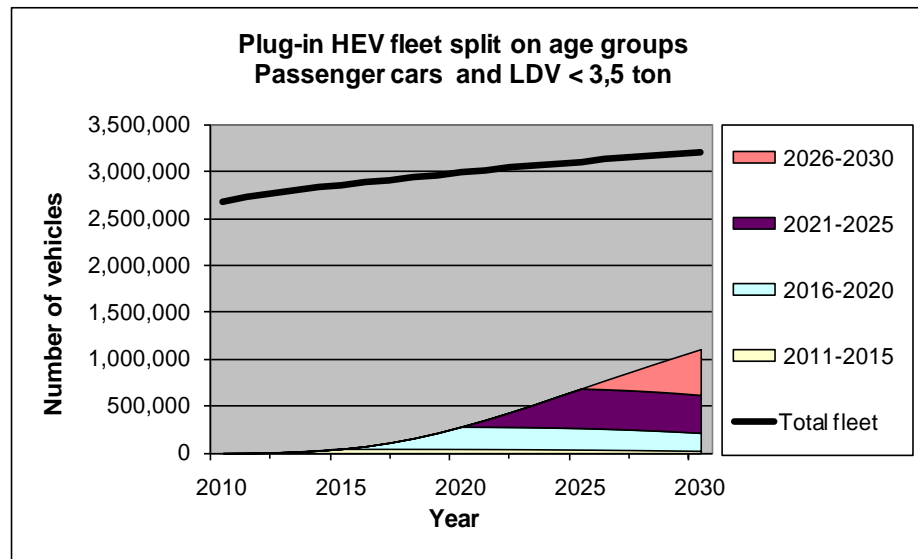
(# PHEVs)

Segment: Passenger Cars + LDV < 3.5t

PHEV Market share

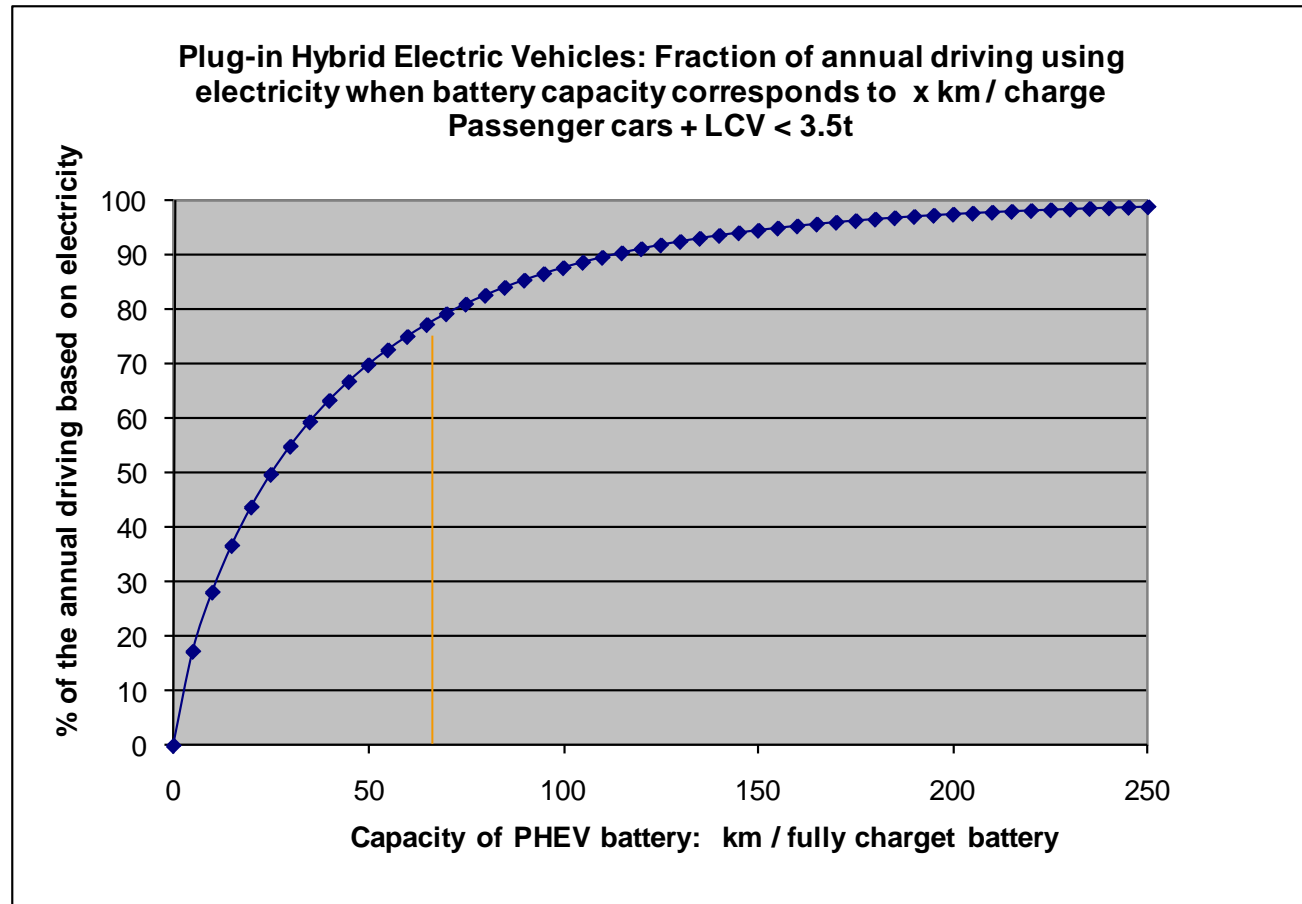


PHEV: Fleet development



Plug-in Hybrid Electric Vehicles (PHEV):

% of annual driving on electricity in DK ?

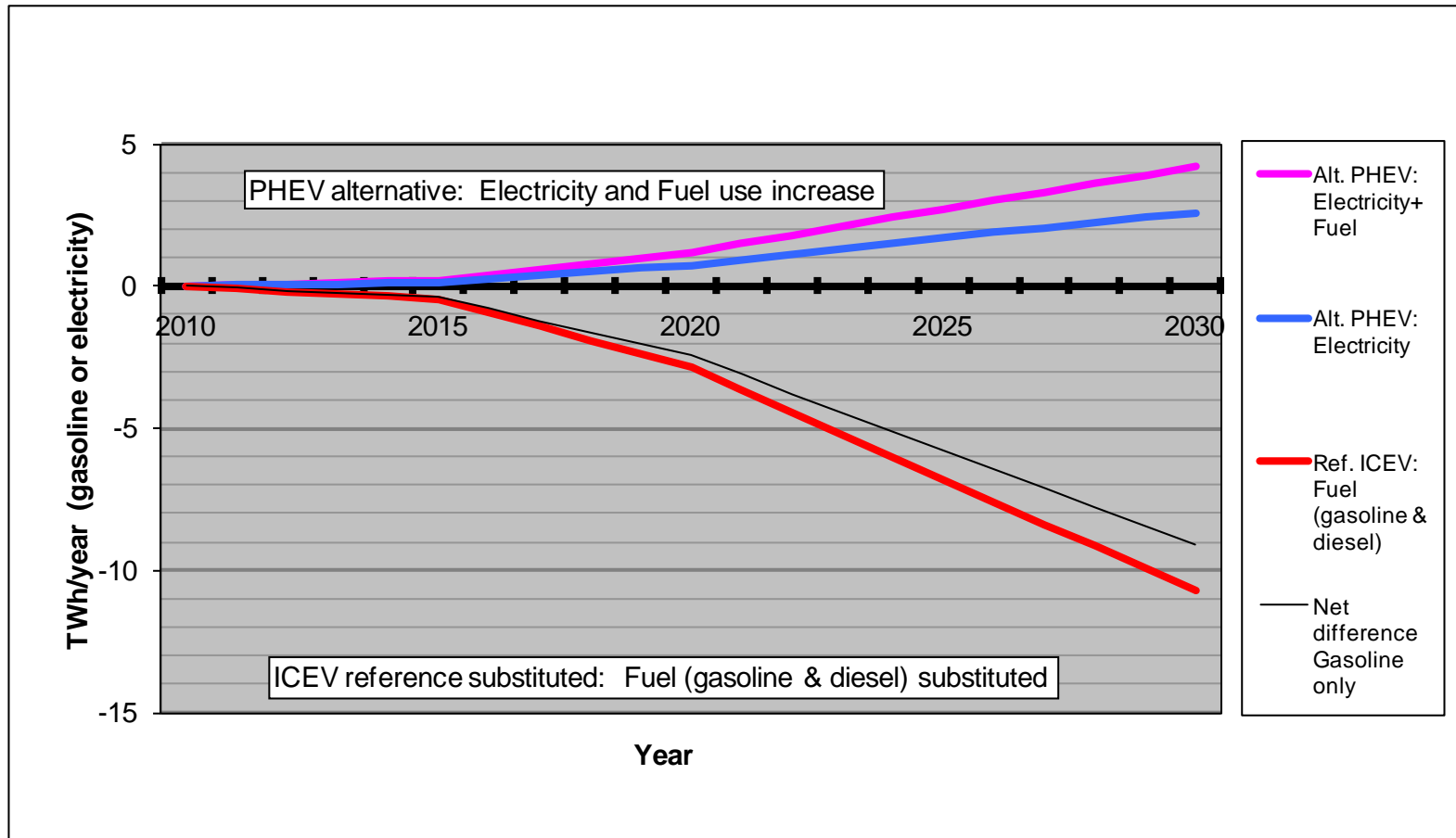


Source: Estimated (Weibull) distribution based on data from DTU Transport: 'Transport Vane Undersøgelse: 2006+2007'.

Danish fleet: PHEV Scenario: Energy substitution

(TWh/year (fuel or el.))

Segment: Passenger Cars + LDV < 3.5t

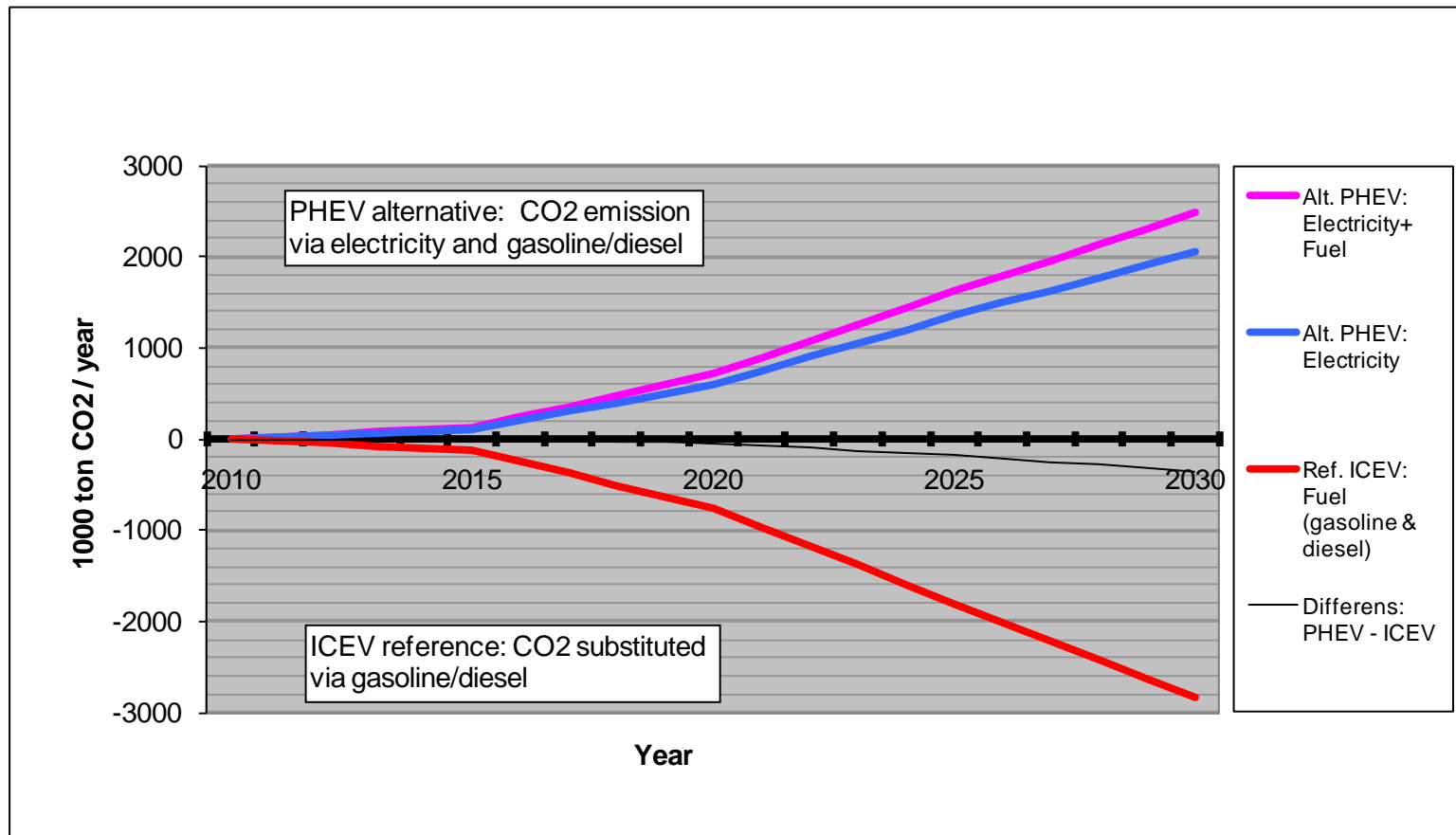


Danish fleet: PHEV Scenario: CO₂ emission

(1000 ton CO₂ /year)

Segment: Passenger Cars + LDV < 3.5t

CO₂Case I : **Marginal (coal based) power supply (DK DEA 2010)**

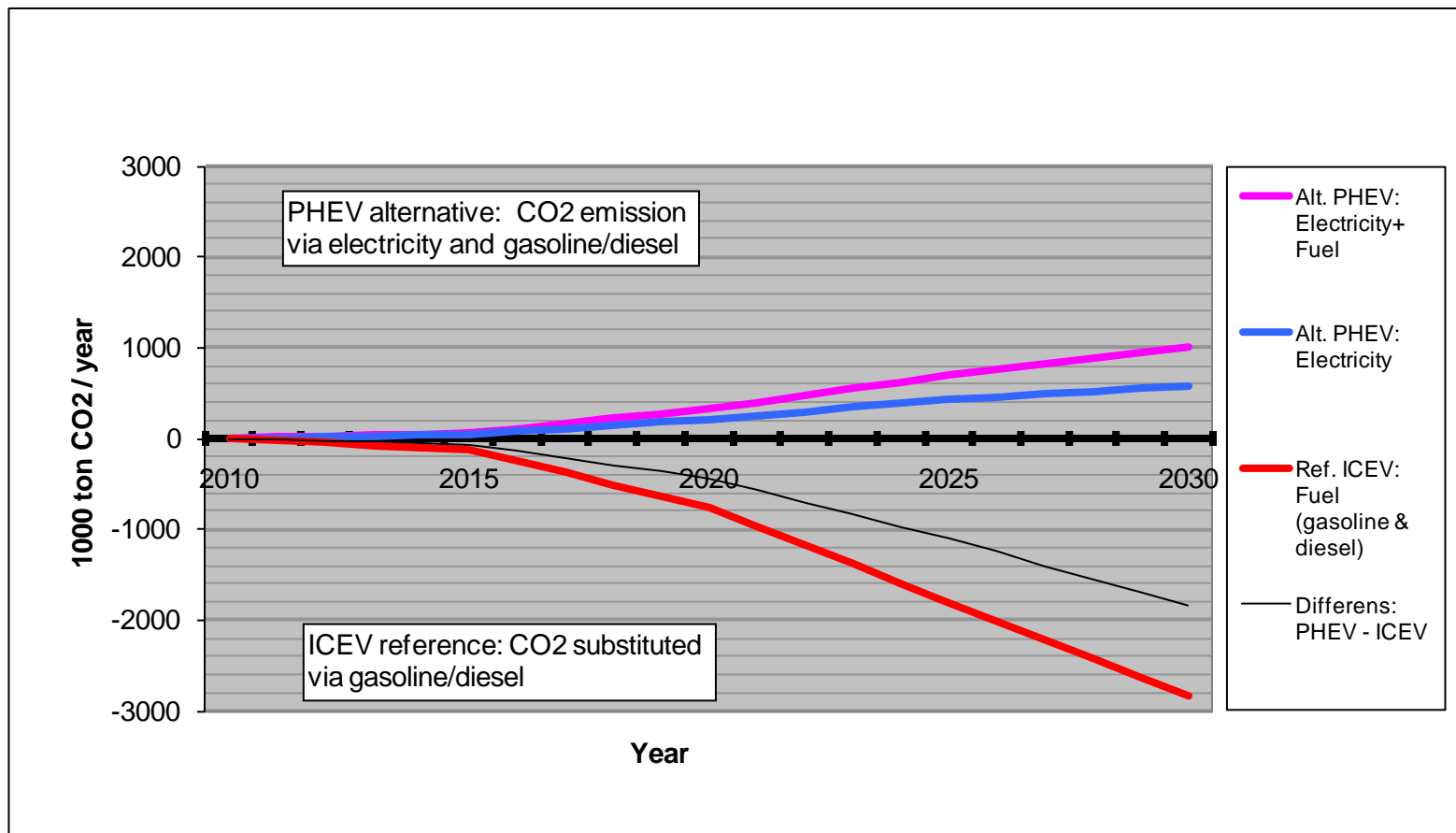


Danish fleet: PHEV Scenario: CO₂ emission

(1000 ton CO₂ /year)

Segment: Passenger Cars + LDV < 3.5t

CO₂Case III : Average power system CO₂-characteristics.
And linear phasing out to zero of all fossil fuels by 2050.



Danish fleet:

PHEV Scenario:

Socio-economic costs of ownership (Mio.\$ /year)

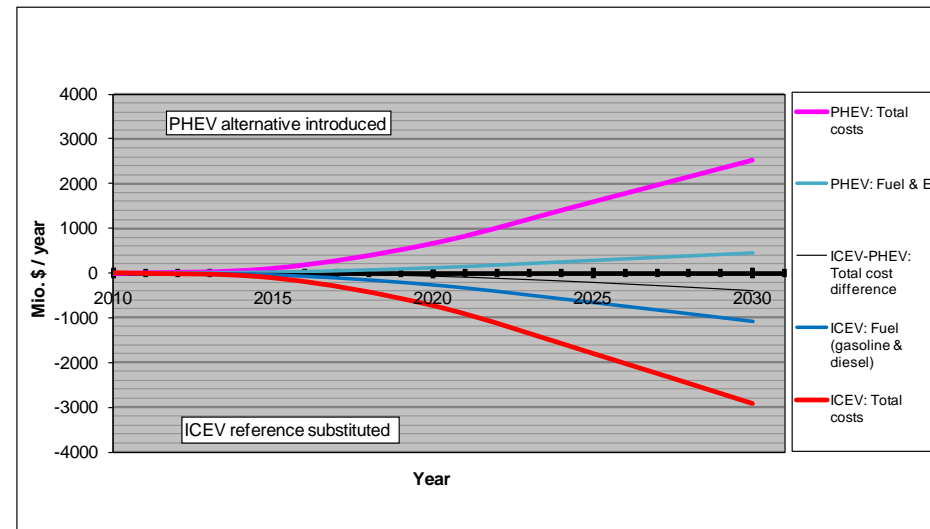
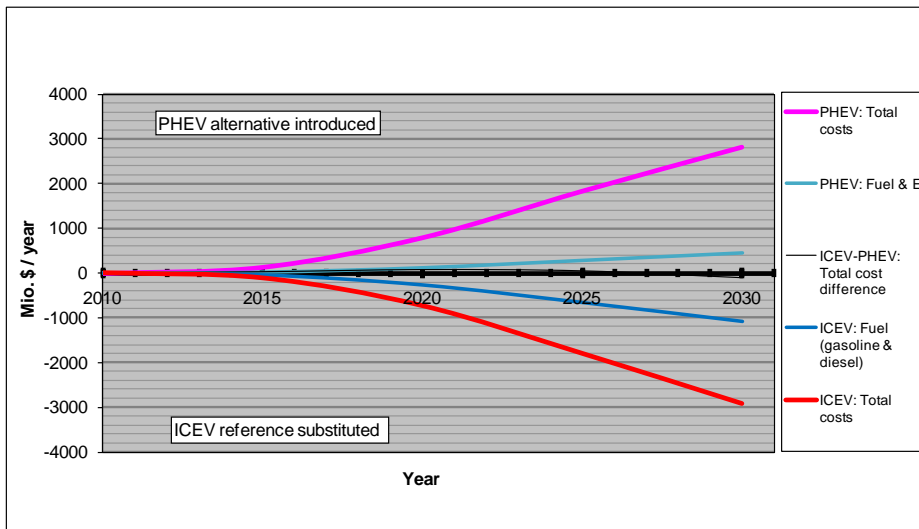
(marginal & partial analysis)



Battery cost development: **Important for BEVs , less for PHEVs**

BatCost I : **Reference**

BatCost II : **US DOE 2010**



Socio-economic PHEV and BEV scenarios: Limitations and assumptions made

- **Issues NOT taken into account:**

- Infrastructure costs
- Insurance costs
- Power system flexibility gains (power system regulation capabilities, postpone investments in production/grids etc.)

- **Externalities NOT taken into account:**

- Reduced local pollution and reduced noise
- Opportunities for industry and future employment ('first mover' effects)
- Oil substitution (reduced dependency on oil)
- EVs effect on hedging for increasing oil prices (and rising transport costs).
- System robustness and flexibility. Security of energy supply (diversified transport energy basis).

Most externalities NOT taken into account tend to act in favor of the EV

Note, however, infrastructure costs for EVs relative to the ICEVs are not addressed in the present analysis.

Thank you for your attention

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